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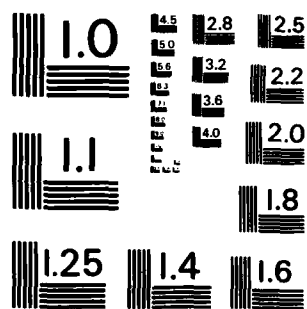UNCLASSIFIED WSRL-0295-TR   F/G 19/1   NL

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TECHNICAL REPORT

WSRL-0295-TR

DESIGN CONSIDERATIONS FOR GUN PROPELLANT CLIMATIC STORAGE CHAMBERS
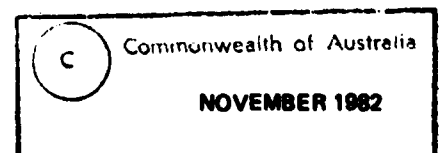
M.R. GRIVELL and A.R. RYE

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WEAPONS SYSTEMS RESEARCH LABOARTORY

TECHNICAL REPORT

WSRL-0295-TR

DESIGN CONSIDERATIONS FOR GUN

PROPELLANT CLIMATIC STORAGE CHAMBERS

M.R. Grivell and A.R. Rye

S U M M A R Y

—>The transfer of responsibility for gun propellant climatic
storage and surveillance from MRL to WSRL required the
design and construction of new climatic storage chambers.
Various design options were considered; the most suitable
used direct electric heating with comprehensive
temperature monitoring and controlling circuitry and was
constructed as a prototype. Experience gained in this
exercise was used in the final design now installed and
operating at WSRL.<—

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1. INTRODUCTION

Propellants made from nitrocellulose are inherently unstable.   One of the
consequences of this instability is the liberation of oxides of nitrogen into
the propellant matrix.   These oxides arise from the thermally-induced
dissociation of aliphatic nitrate ester bonds. This reaction is autocatalytic
in nature, so the useful life of such propellants can be substantially
increased by incorporating chemical compounds which remove the nitrogen oxides
by chemical reaction.   These   compounds, called stabilizers,   include
diphenylamine, ethyl   centralite   (2,2'-diethylurea)   and   p-nitro-N-
methylaniline.   The chemical reactions associated with stabilizer action are
discussed in references 1, 2 and 3.

Among the techniques used to estimate the useful service life of a gun
propellant is its storage at elevated temperatures with periodical estimation
of residual stabilizer content.   Calculations can then be made, based on the
accelerated degradation of propellants at high temperatures, which allow
limits to be set to the service life. A technique which has gained acceptance
in many countries requires storage of gun propellants in glass tubes at a
constant temperature of 49°C,   with analysis of remaining stabilizer at
specific intervals(ref.4).   This test was adopted about thirty years ago by
Australia   and was   set up   and   carried out   by Materials   Research
Laboratories(MRL). During the late 1970's, however, the responsibility for
these tests was transferred from MRL to Weapons Systems Research Laboratory
(WSRL) and this required the 49°C climatic storage chambers to be relocated at
WSRL.   The MRL chambers were not transportable because of deterioration and so
the opportunity was   taken to design and construct   chambers at WSRL
incorporating modern techniques and materials. Prior to the transfer of
responsibility of this task, MRL had carried out some preliminary analysis
which was   utilised and   expanded.   This   report details   the design
considerations and ultimate construction of the chambers.

2. PRINCIPAL CLIMATIC CHAMBER REQUIREMENTS

2.1 Thermal environment

The main purpose in the construction of the chambers was to maintain a
stable thermal environment for gun propellants stored in glass tubes.   The
specification calls for temperature control in the range of 49±3°C but it
was felt that better precision was desirable.   The goal was to achieve a
stable target temperature of 49°C with differentials throughout the chamber
of less than ±1.0°C.   Associated with this requirement was a need for
optimum thermal insulation and a high heat capacity, the former to minimise
energy requirements and the combination to reduce rate of temperature
change in the event of power interruption.

2.2 Safety

The intended use of these chambers at full capacity involves the storage of
large quantities of inflammable gun propellants and therefore the highest
consideration needed to be given to all aspects of safety.   DRCS Safety
Section was involved in discussions at all stages of the design evolution.
Opinions were also sought from other DRCS personnel with a background in
safety matters.

3. EARLY DESIGN STUDIES

The following design options were considered by MRL(ref.5) during the early 1970's.

3.1 Circulating hot water system

A circulating hot water system requires the construction of a climatic chamber with a conducting water jacket, supplied from an external hot water source. The advantages of such a system are:

(a) temperature control of the inlet water is simple and immediate,

(b) the heat source is remote from the chambers,

(c) a 'fail-safe' design to prevent overheating can be readily achieved.

The disadvantages of the circulating hot water concept are:

(a) adequate thermal contact between the jacket and the external surface of the chamber proper requires very careful design of the manifolding,

(b) it is very difficult to guard against the existence of undesirable thermal gradients in the chamber,

(c) water leakage could damage the propellant samples.

3.2 Forced air system

A ducted fan-forced hot air design has most of the characteristics of a circulated-water system except that leaks are not so crucial. An additional advantage is that the heated air could be circulated freely through a 'honeycomb' of propellant tubes, which could lead to more even temperature conditions. However, the proper siting of temperature monitors and design of control circuitry could be quite complex. Also, the construction of inlet manifolds would require careful attention to ensure that proper distribution of the airflow took place.

3.3 Direct electric heating

Initially, safety reservations precluded consideration of the inclusion of electrically-powered elements within the climatic chambers. However, it soon became evident that such a concept had the potential to overcome many of the design and control problems associated with the use of hot air or water.

The advantages of electric heating are:

(a) excellent thermal contact

(b) potential for low thermal gradients

(c) straightforward monitoring and control requirements

(d) easy maintenance

Problems associated with this technique include the potential for arcing and its inherent hazards.

4. EARLY EXPERIMENTS

The advantages of direct electric heating were considered to be very attractive so a small laboratory test chamber (figure 1) was constructed at MRL. It was a 30 cm cube fabricated using 12 mm thick aluminium plate. Two hundred turns of nichrome wire of appropriate resistance were wound around the outside. The box was then encased in 37 mm thick foamed polystyrene. A number of thermocouples were placed on the six internal surfaces and within the chamber.

Figure 1. *Laboratory test chamber*

Heat-loss calculations for this test chamber were carried out using the conventional thermal conduction equation:

$$Q.x = k.A.t.\Delta T \tag{1}$$

Where Q = heat transferred from inner surface to outer surface (J)
      x = insulation thickness (m)
      k = specific conductivity of insulation $(J.m^{-1}.s^{-1}.{}^{o}C^{-1})$
      A = surface area (m^2)
      t = time (s)
      ΔT = temperature gradient $({}^{o}C)$

The power consumption of the test chamber element agreed well with calculations based on equation 1. Thermal gradients were small, and long-term temperature stability (after equilibration) was excellent.

5. WSRL PROTOTYPE

The construction of the full-sized WSRL prototype chamber was based on experience gained with the laboratory test chamber. First, a number of issues relating to the components of the facility had to be resolved.

5.1 Power source

The original intent was that the elements would be heated by a low-voltage d.c. current drawn from a continuously-charged bank of nickel-cadmium batteries. As the design evolved, however , it became clear that a stepped-down mains a.c. supply was perfectly acceptable. This allowed the

selection of a simple motor-driven generator as a back-up power source.

5.2 Insulation

The insulation material chosen was a polyisocyanurate foam known commercially as 'Isothex' or 'Hexafoam'. This insulant has high strength and rigidity, allowing it to be lightly supported in the framework. In addition, it has very low thermal conductivity, and high resistance to combustion. It has an oxygen index of 30% and will not burn in air.

5.3 Chamber structure

Careful attention was given to the basic requirements of the chamber 'core'. In essence, these are:

   (a) minimum weight, consistent with structural strength

   (b) free airflow around tubes of propellant

   (c) provision for installation of electric elements

   (d) minimisation of protrusion of structural members through the insulation material.

The core design eventually selected is illustrated in figure 2. Each core is 1860 mm high, 1015 mm deep, and 850 mm wide.
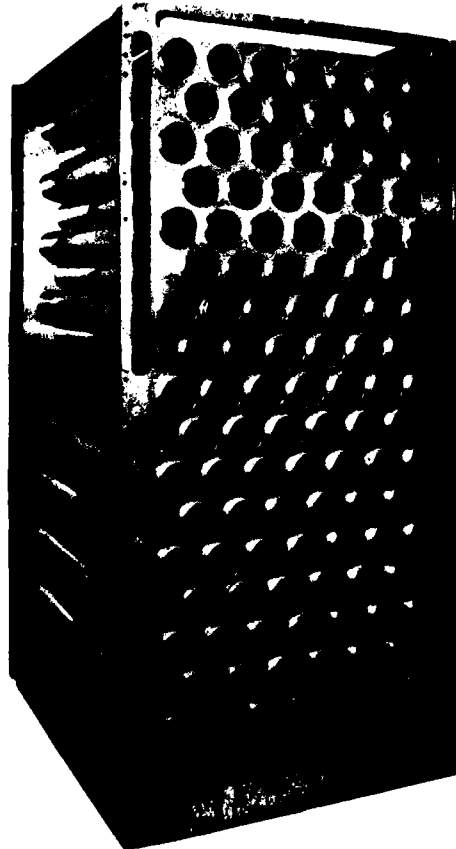

Figure 2. Climatic chamber core structure

This design incorporates 111 thin-walled aluminium alloy tubes arranged in a 'honeycomb' array which are installed between holes in the front and back plates.   The gun propellants, in stoppered glass tubes, are inserted in these receptacles.   Six slots (two on each vertical side, one each on top and bottom surfaces) and guide rails are included to allow easy insertion and removal of element plates (see Section 5.4).   A typical climatic chamber consists of three of these basic cores, separated by and clad with foam insulation.

5.4 Direct electrical heating element

Figure 3 is a schematic diagram of one of the heating elements.   Each of these is a monolithic aluminium alloy plate which is cast with an integral 'Pyrotenax' heating element.   This element is laid out within the plate in serpentine fashion, giving even thermal coverage to the whole surface of the plate.   Each plate contains two monitoring devices; a sensor which is connected to the controlling circuitry, and an over-temperature safety cut-out.
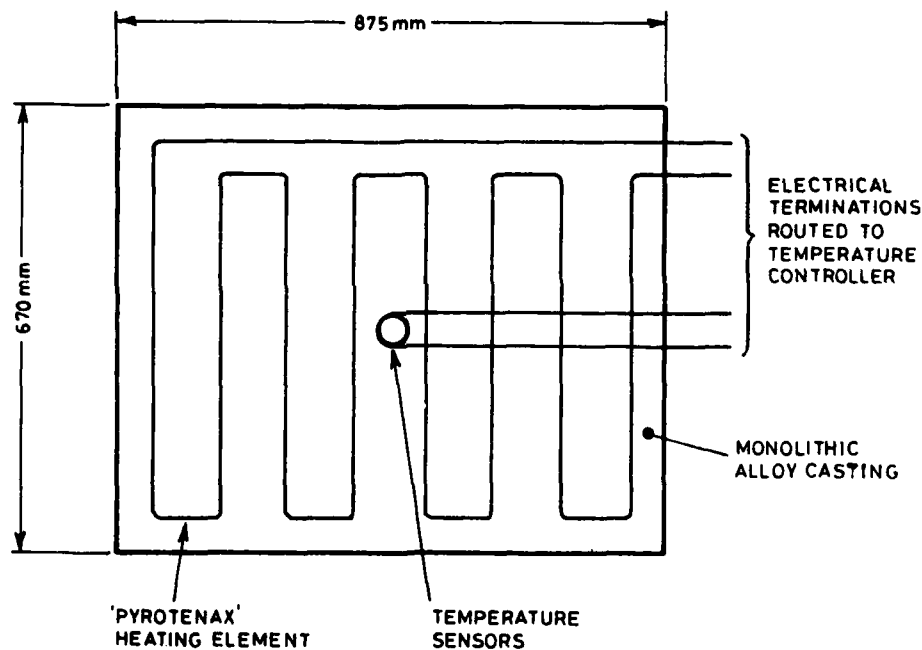

Figure 3.   Schematic diagram of thermal element

Figure 4 is a photograph of a prototype element which has certain parts of the design exposed for clarity.

This photograph is of special interest as it shows quite clearly the positions of the temperature sensors and the manner in which connections to the 'Pyrotenax' element are made.   All electrical terminations are made at a shielded lockable connector.

Figure 4.   Prototype thermal element

6.   TEMPERATURE CONTROL

6.1 Power requirements and thermal monitors

Power to each chamber is supplied by a 415V/110V, 2.64 kVA 50Hz three phase transformer that is connected 'delta to star'.   Each phase of the transformer supplies power to two heater plates.   Each plate is powered through a triac and temperature control circuit as shown in figure 5. Figure 6 is a photograph of an assembled power control module.

The temperature control device (figure 7) depends for its operation on two thermistors mounted centrally in the heater plate.   Each thermistor (ITT type GT52C) is a thermally-sensitive resistance bead suspended in a glass pellet mounted in a metal can having a resistance-temperature characteristic as shown in figure 8.
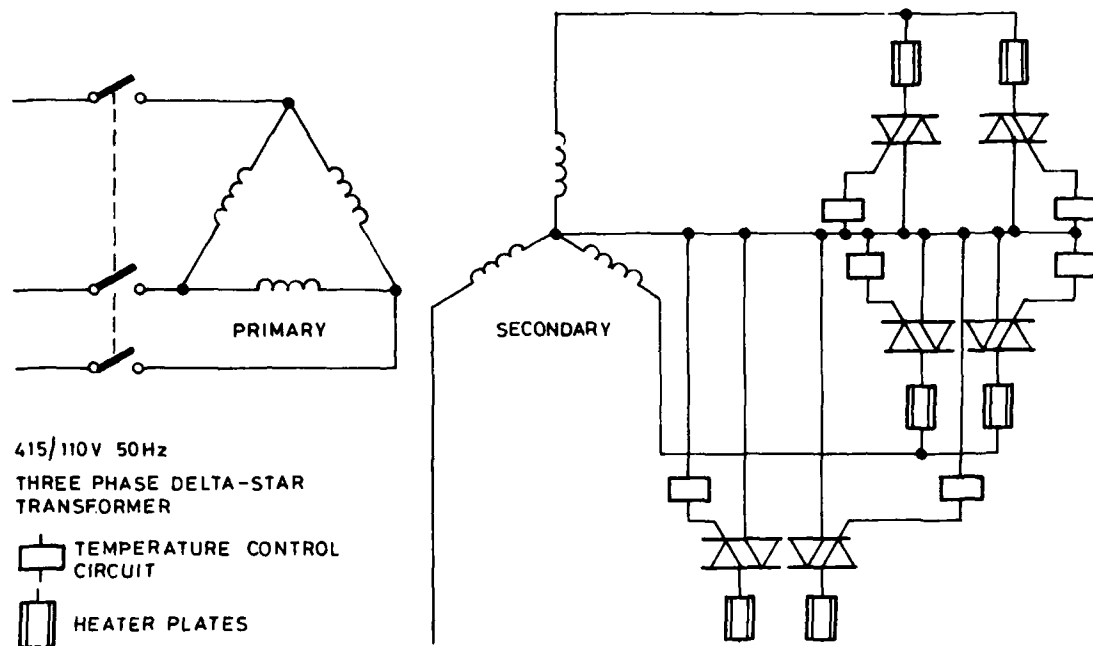
415/110V 50Hz

THREE PHASE DELTA-STAR
TRANSFORMER

TEMPERATURE CONTROL
CIRCUIT

HEATER PLATES

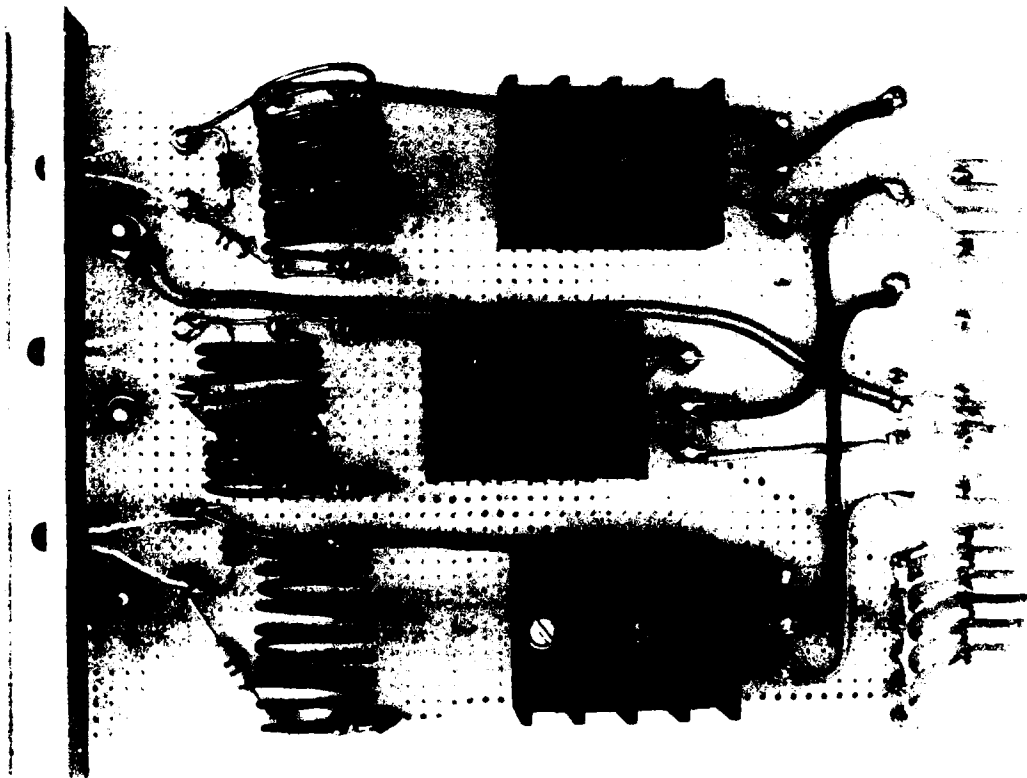Figure 5.   Power control circuit diagram
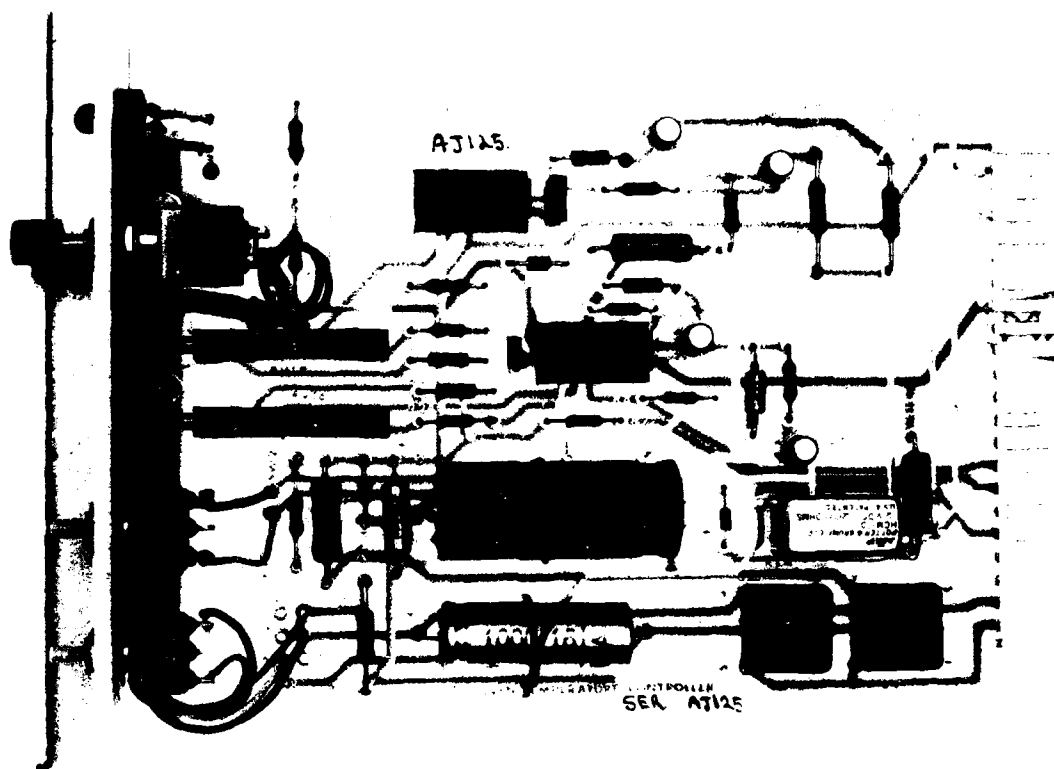

Figure 6.   Power control module

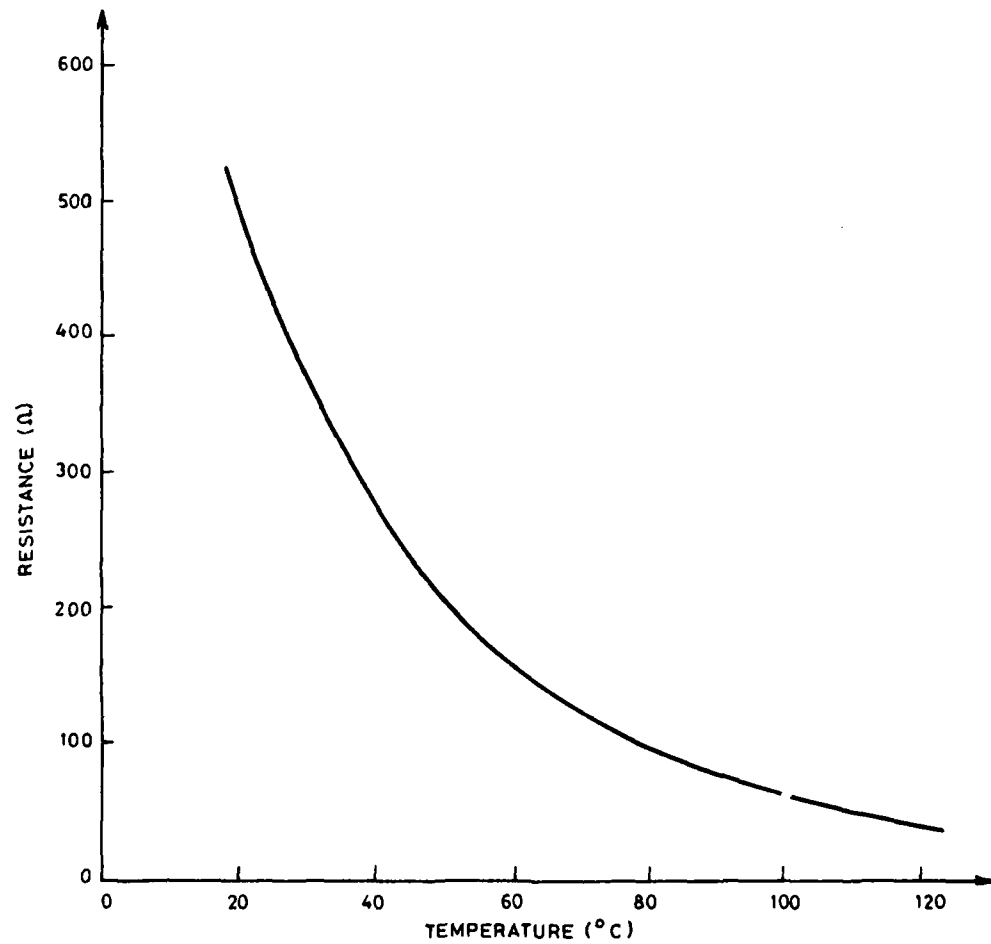Figure 7.   Temperature control module

Figure 8.   Thermistor (Type GT52C) resistance-temperature characteristic

One of the thermistors is the sensor for the temperature control circuit
and the other is the sensing element for the over-temperature control
circuit - a safety feature to prevent overheating of the heater plate if a
fault occurs. This device monitors the temperature of the heater plate and
isolates the power from it if a preset over-temperature condition occurs.
An indication that an over-temperature condition exists is given by a LED
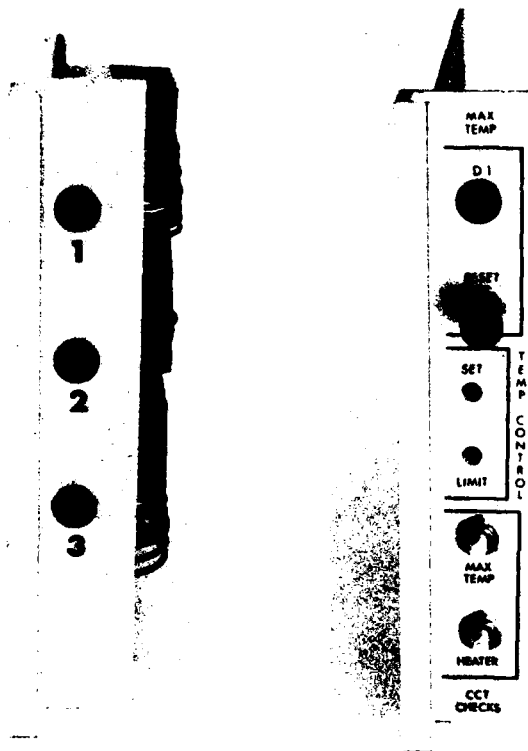mounted on the front plate of the temperature controller board (figure 9).

Figure 9. Front plates of power and temperature controller boards

6.2 Temperature controller

A schematic circuit diagram of the temperature controller is shown in
figure 10. Full details, including components, are given in reference 6.

The full wave rectifier output voltage of bridge rectifier network V9 is
capacitively filtered by C2 and the resistance-zener diode combination
provides a regulated voltage for the bridge network R3, R26, R4, R21, R17
and R22.   R17 is a 10 kΩ potentiometer which sets the desired temperature
for the heater plate and R26 is the thermistor which is mounted in the
centre of the heater plate.

At power-up, the heater plate will be at ambient temperature and below the
set temperature (49°C).   The resistance of the thermistor will be high and
so the voltage at pin 4 of the voltage comparator N1 will be more positive
than the set temperature voltage at pin 3 and the output voltage of N1 at
pin 9 will be low, resulting in the transistor V4 being turned off and the
transistor emitter-follower V5 being turned on.   The emitter voltage of V5
is fed via the normally closed relay contact RLA/2 to the gate of the
triac, and, as the emitter voltage of V5 is high, the triac conducts on
each half cycle of the 110V a.c. input supplying power to the heater plate,
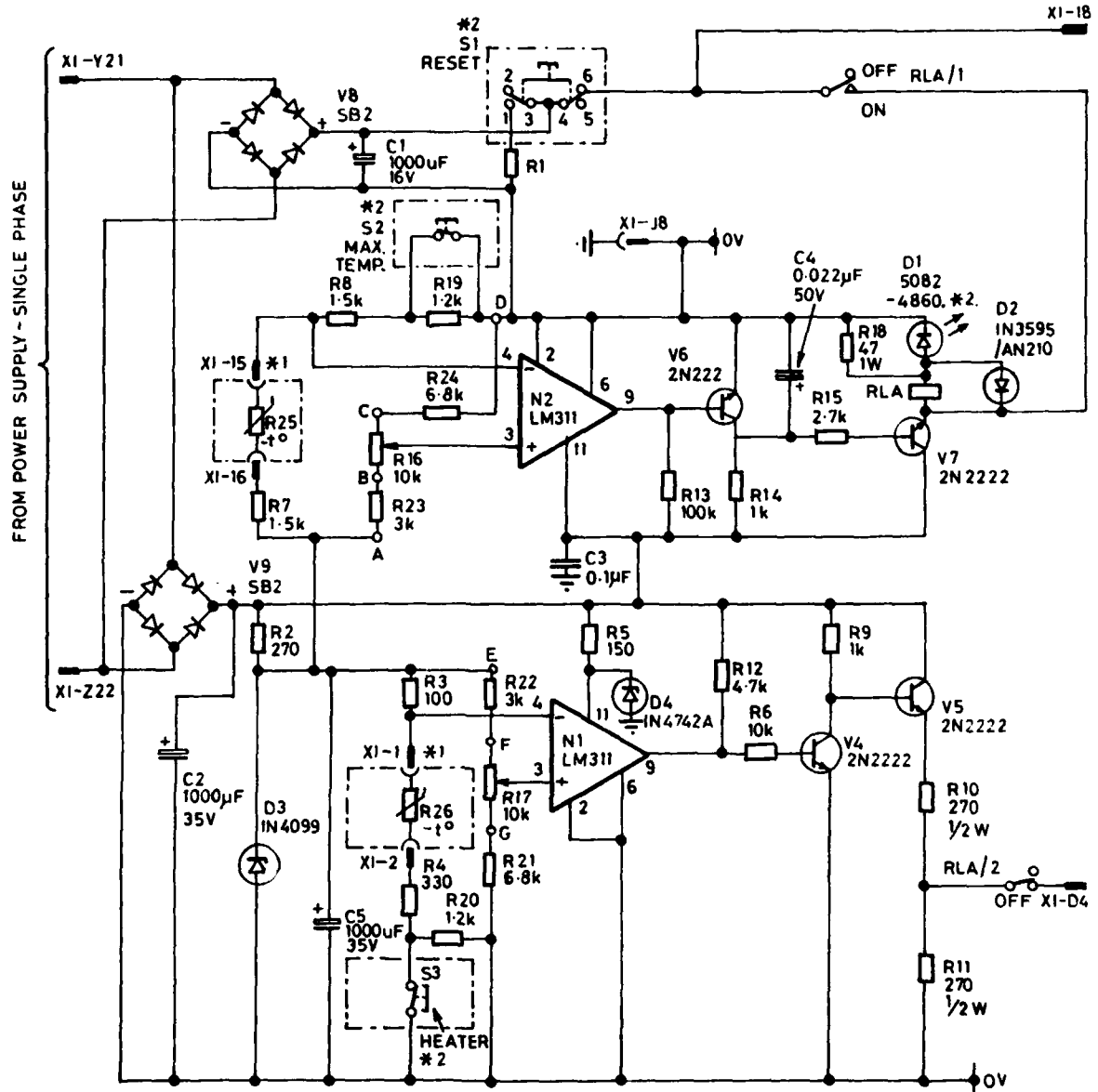and the plate begins to heat.

NOTE - *1 FITTED TO OVEN HEATER PLATE
       *2 FITTED TO FRONT PANEL

Figure 10. Schematic diagram of temperature control circuit

When the temperature of the heater plate reaches the preset temperature, the resistance of the thermistor reduces to a level where the voltage at pin 4 is below the voltage at pin 3 and the output voltage at pin 9 of N1 switches from a low value to a high value causing transistor V4 to turn on and transistor V5 to turn off. The gate voltage of the triac is now too low for conduction of the triac to take place and heating of the plate ceases. When the triac is conducting, the appropriate LED mounted on the front panel of the triac card (figure 9) indicates that the particular plate is being heated.

6.3 Over-temperature control

The bridge network R7, R25, R8, R24, R16 and R23 is supplied by the regulated voltage of zener diode D3, and potentiometer R16 sets the temperature at which the over-temperature circuit is to operate. At temperatures below the preset temperature, the resistance of thermistor R25

is high and the voltage at pin 4 of the voltage comparator N2 is negative with respect to the preset voltage on pin 3 and the output voltage of N2 at pin 9 is high causing transistor V6 to be turned on and transistor V7 to be turned off. As the temperature of the heater plate rises, the resistance of R25 falls and the voltage on pin 4 of N2 becomes more positive. If a fault in the temperature control circuit occurs and the temperature of the heater plate reaches its preset value the voltage on pin 4 rises slightly above the preset voltage on pin 3 and the output on pin 9 rapidly falls to a low value. This causes transistor V6 to switch off and transistor V7 to turn on operating relay RLA and LED D1. With RLA operated, the normally open contact RLA/1 closes and voltage from the full wave rectifier bridge network V8 is supplied through the reset switch S1 and the self locking closed relay contact RLA/1 to the relay coil causing it to remain in the operated condition. At the same time, the normally closed contact RLA/2 opens removing voltage from the gate of the triac preventing any further heating of the heater plate. This condition continues until the fault has been removed and/or the reset switch S1 has been activated.

The LED D1 indicates that an over-temperature condition has occurred.

6.4 Checks on control circuits

Appropriate test circuits have been incorporated in the equipment to ascertain its serviceability on a day-to-day basis. The temperature control circuit board includes:

(a) Heater plate controller

To check the operation of the heater plate controller, momentary action of switch S3 mounted on the front panel (see figure 9) and marked 'HEATER' is required. Operation of this switch introduces a resistance R20 into the branch of the comparator bridge network containing the thermistor R26, and the voltage on pin 4 of N1 falls below the preset voltage on pin 3. This causes the triac to conduct on each half sine wave of the supply voltage and this is indicated by the LED mounted on the front panel of the temperature controller.

(b) Over-temperature controller

To check the over-temperature controller, activation of switch S2 mounted on the front panel, and marked 'MAX TEMP', is required. Operation of this switch introduces a resistance R19 into the branch of the comparator bridge network containing R7, R25 and R8 and causes the voltage on pin 4 of N2 to increase slightly above the preset voltage on pin 3. The circuit then operates as if it had detected an over-temperature condition and this is indicated by the LED mounted on the front panel of the temperature control card. Operation of the reset switch S1 mounted on the front panel, removes the voltage from the relay coil RLA allowing the circuit to return to its original state.

7. ASSEMBLY AND PERFORMANCE

Test-bench trials of individual heater plates with interim-design temperature control circuits displayed excellent thermal characteristics. Individual insulated plates displayed a variation in surface temperature of ±1.5°C when set for temperatures between 40-75°C. These results were so encouraging it was decided to manufacture a full-size operating climatic chamber.

A bank of three cores, each as shown in figure 2, was assembled into a steel framework with insulation fitted into the interstices. The heating plates and

associated wiring were installed. A photograph of the prototype at this stage
of assembly is shown in figure 11.   The wooden vent plugs seen in the
photograph were used to simulate the effect of sample tubes.

Each chamber was clad in thin alloy sheet and the front was closed with twelve
drawer-type insulated doors secured by magnetic latches.   This aspect is
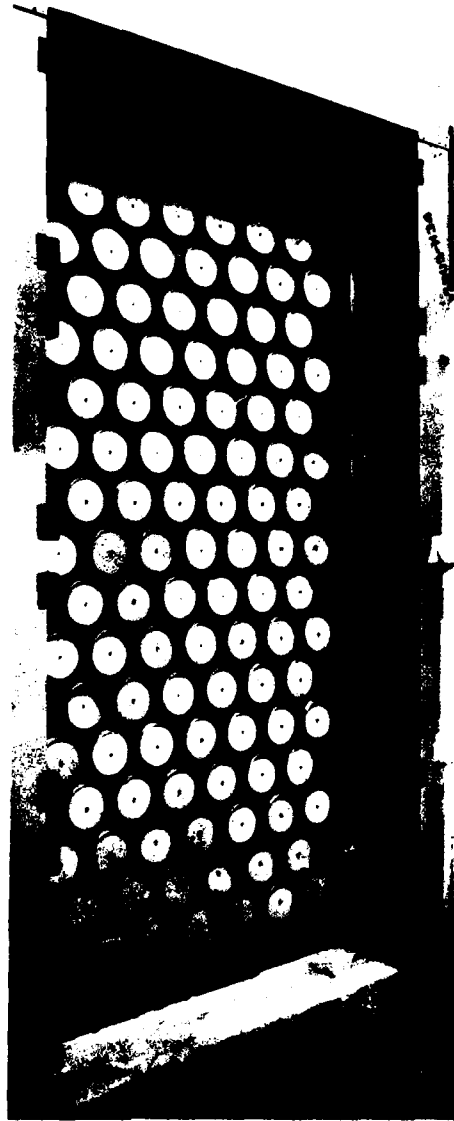illustrated in figure 12.

Figure 11. Assembled prototype chamber

Twelve thermocouples were mounted at various points within the central chamber
of a triple-chamber assembly.   Three other sensors were placed externally to
monitor surface temperatures and ambient conditions.   The chamber achieved
operating temperature within ninety minutes of power-up, and over a three-day
test period all internal thermocouples displayed individual variations of less
than 0.5°C. A consistent thermal pattern emerged, as expected, with a thermal
gradient extending from the upper region of the chamber to a cooler zone at
the base.   This temperature gradient was never greater than 2°C and usually
about 1°C.

The performance of this prototype chamber was perfectly acceptable for routine
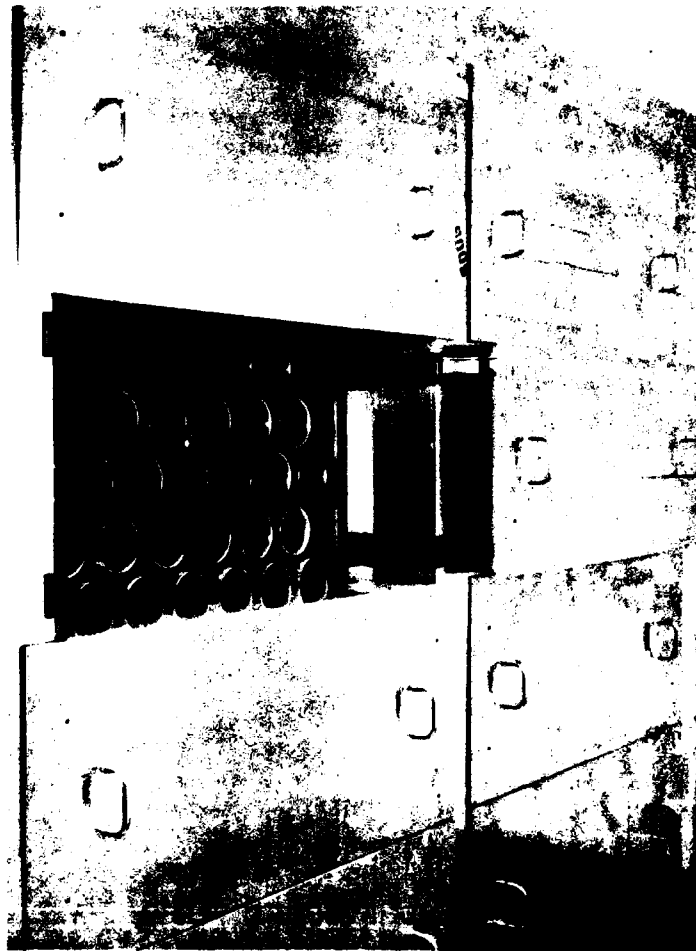
Figure 12. Front view of assembled prototype

climatic storage testing of propellants. After some minor attention to design
detail, it was brought into service in late 1978.

Two years experience led to a refinement of the design in 1980.   Improvements
to insulation installation and careful matching of the temperature control
circuits to individual thermal elements has resulted in overall temperature
gradients of better than ±0.5°C being achieved.   In addition,   the current
chambers are fitted with hinged doors with integral insulation as shown in
figure 13.   This has improved sample accessibility and reduced thermal losses
through reduction in the number of seals required.

8.   CONCLUSIONS

Direct electric heating has proved to be an efficient and flexible means of
providing a stable thermal environment   for gun propellants undergoing
assessment   by   the   long-term   climatic   storage procedure.   Chambers
incorporating this form of heating, controlled by electrical circuits capable
of maintaining both a stable temperature and safe operating conditions, have
proved to be a significant improvement over earlier designs.   Energy
consumption at equilibrium is low, and thermal stability is excellent.

Figure 13. Final chamber design

9.   ACKNOWLEDGEMENTS

The early experiments which provided the original basis for this work were
carried out at Materials Research Laboratory, Maribyrnong.   In particular,
substantial contributions were made by Mr S. Thomas and Mr D.R. Sadedin.

The authors wish to express their thanks to the personnel of the Engineering
Workshops of Advanced Engineering Laboratory for advice and assistance in the
manufacture of these chambers, and especially to Mr M. Koldowski of AEL Test
Section.

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16	SUMMARY OR ABSTRACT:

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The transfer of responsibility for gun propellant climatic storage and surveillance from MRL to WSRL required the design and construction of new climatic storage chambers. Various design options were considered; the most suitable used direct electric heating with comprehensive temperature monitoring and controlling circuitry and was constructed as a prototype. Experience gained in this exercise was used in the final design now installed and operating at WSRL.

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Technical   Intended primarily for disseminating information within the DRCS. They are
Memoranda   usually tentative in nature and reflect the personal views of the author.

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